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ASSESSMENT OF ENVIRONMENTAL RESOURCES FOR VINEYARDS MICROZONING BY GIS

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Abstract

Nowadays making decisions quickly and selecting the best alternative are very important for location of agricultural crops to gain competitive advantage in a complex environment. In this research, multi-criteria decision analysis with pair wise comparison weighting method was utilized to determine the suitable locations for vineyard plantation in Karlovo region, Bulgaria. Soil maps, meteorological measurements, slope, aspect, elevation maps were used as input to conduct spatial analysis. AHP method is compared with previous investigation and the pair wise comparison research is identified as a better one for the spatial analysis by GIS. In this study GIS multi-criteria evaluation for zoning and exploration sites presents the potential vineyard location in the research area.

Key words*: AHP, GIS, microzoning, multi-criteria analysis, vineyards.*

INTRODUCTION

Vineyards are wildly spread farming systems, combines different and comprehensive conditions of natural resources to achieve a high-quality production. Grapes and wine are natural products whose special characteristics depend on environmental conditions. Viticulture has a strong association of place and time. Many factors and complex relationships of variables influence to the final results for different regions.

The uniqueness of the great wine terroirs of the world has been built up on the basis of right combination of climate, soil and terrain in general. Viticulture zoning and site selection for potential vineyards are becoming important in the context of growing wine markets and emerging wine producing regions in Bulgaria beyond the limit defined by certain vine requirements (Bramley et al., 1999).

Most researchers believe the same reasons are behind the secret of French wine (Willson, 1998) and best wine *terroirs* of the world (Fanet, 2004; Winkler, 1962), because grape quality and yield highly depend on the micro-, meso- and macro climatic conditions formed by the surrounding environment (Jackson, 2008) and the soil characteristics (White, 2003). Site selection for the expansion or the establishment of new vineyards is one of key aspect of viticulture zoning (Vaudour et al., 2005).

The quality of wine depends on the quality of the grapes and it is determined by their environmental and growing conditions, referred to as '*terroir*' by the French (Wilson, 1998). A broader meaning (of *terroir*) includes a combination of vineyard location, soils, climate, and other environmental factors, as well as choice of grape varieties, viticulture practices, and the strategies of the producers – natural as well as human characteristics (Moran, 2001; Deloire et al., 2005). Location or spatial references are important to many of these factors. Results are determined by environmental effects, and by the analyses, decisions and actions of the grower. Vineyards cultivation takes advantage of natural factors - such as soils, climate, altitude, slope, aspect, by selecting suitable sites for particular vine varieties. They control or manipulate other factors through management procedures (Smith, 2002).

The quality of available information is an important factor determining the quality of decisions made and, therefore, the quality and profitability of results. Much of the information and processes relate to location, so spatial (geographical) relevance is a significant aspect of vineyard data. Physical conditions vary across landscapes at all scales (Voltz, 1997). As the success of agricultural production depends on these conditions, analyses of the associated information and understanding of their

variability, using spatial information systems to support decisions and management responses to them, offers opportunities to improve results (Smith, 2002).

Site selection requires a system that gathers and makes accessible the types and ranges of information that a viticulturist will use in decisions, to optimise the selection of sites. It needs to correlate and compare the factors & constraints that are significant to vineyard development and performance, especially the factors that vary spatially (Tonietto et al., 2004). It will be a system to integrate spatially based information from a variety of sources, to allow selection, combination and analysis of important factors, in an integrated manner (Badcock, 1998; Malczewski, 1999).

Precision agriculture and site-specific farm management have demonstrated the successful tools of spatial information systems and related technologies in primary production - crops from the land, and the management and use of resources (Hall et al., 2002). The selection and establishment of a suitable site is probably the most important, fundamental, irreversible decision in the life of a vineyard (Gladstones, 1992; Pool, 2001; Roberts, 1999). It is speculated that this process will be enhanced systems along with multi-criteria analyses, decision support and management systems.

The using of GIS database in vineyards management will help to increase the knowledge of the vine farming relating with the selection of areas, selection of suitable productions direction and varieties and applying of good agricultural practices for sustainable vine production sector. The future perspective tools like GIS gives us opportunity to modelling with a huge amount of different king of information. It contains interdisciplinary information that involves integration of criteria from different branches of science. Some case studies in the references cited also discuss potential uses for GIS in site selection and they do point out potential benefits (Badcock, 1998; Kirkby et al., 1996).

MATERIALS AND METHODS

This paper proposes that the process of vineyards site selection will be achieved and the probability of success improved, by the use of spatial information systems combine with multi-criteria analyses, decision support and management systems. The processes will need to include criteria and factors that are important in selecting a site and establishing the vineyards.

In this research, multi-criteria decision analysis with pair wise comparison weighting method was utilized to determine the suitable locations for vineyard plantation in Karlovo region of Bulgaria. Soil maps, meteorological measurements - temperature, irrigation, topographic components- slope, aspect and elevation were used as input to conduct spatial analysis.

The methodology is based on a Geographic Information System (GIS) analysis of the most important ecological parameters, representative of the topography, climate and soils in the continental climate vineyards. Weighted decision-making analyses by using suitable coefficients of each criteria present relative importance of particular environmental factors or constraints (Malczewski, 1999).

The necessary information is gathered by different sources as the soil distribution maps, elevations models, temperature distributions, depends on the vine crops requirements about the land use for suitable vineyards zoning. All data is transformed and realized by using spatial analysis and systems in GIS platforms.

The results are done by complex combination of the Analytic Hierarchy Process (AHP), GIS tools and spatial distribution of different parameters and vineyards management for multi environmental assessment of suitability sites and profitable future results.

The Analytic Hierarchy Process (AHP) is a well-known multi-criteria decision-making method, proposed by Saaty in 1980 (Saaty, 1980; 1996; 2001). The method provides a theory of relative measurement of various criteria for decision analysis (Saaty, 1990; 2005). The Analytic Hierarchy Process consists of the decomposition of the decision problem into simpler components or levels and the definition of a hierarchy framework by pair wise comparison between the levels.

The top level of the hierarchy is the goal of the decision problem- environmental assessment of vineyards zoning. The next level consists of the main criteria and sub-criteria used to assess the

alternatives, which in turn, form the bottom level of the hierarchy. AHP uses pair wise comparisons to assign weights to the individual elements of each level, by measuring their relative importance using Saaty´s 1-9 scale, and then calculates the overall priority for the alternatives of the decision process (Saaty, 2008). The method also calculates a consistency ratio associated with each matrix of pair wise comparisons to verify the consistency. The mathematical foundations of the method can be found in Saaty (1977; 1994).

RESULTS AND DISCUSSIONS

Selection of potential sites for a new vineyard for wine production is a complicated and important decision as several factors have influenced on it. This research paper deals with a methodological approach based on GIS multi-criteria evaluation for zoning and exploration of potential vineyard sites in the Karlovo region, Bulgaria. Among several indicators proposed in the methodology, environmental factors are calculated to show implementation of the AHP methodology for zoning and to assess the prospective outcomes of the viticulture research.

Nowadays making decisions quickly and selecting the best alternative are very important for vineyard farming to gain competitive advantage in a complex environment. Therefore, the suitable vineyard location selection is considered in this paper. Because this selection affects the quality of wine as the grape quality affects the wine quality directly. Selection of vineyard location is a specific multi-criteria decision problem and the conventional methods for resolve suitable vineyard site location problems are deficient for dealing with the insufficient or unclear nature parameters of environmental assessments. This paper attempts to solve the vineyard location selection problem by adopting the method of analytic hierarchy process (AHP) and multi-criteria decision making (MCDM) method into GIS platforms. After determining the criteria and alternatives that affect the vineyard location decisions, these methods are used to solve the problem and results are presented by the thematic suitability map.

The study region Karlovo is being analysed in some past researches (Arnaudova et al., 2010; 2011; Popov et al., 2010; 2011) and illustrated vineyard microzonig for determination of three branches of wine production - red wine, white wine and dessert grape. The articles show the suitable territories analysed with distribution of some initially parameters of natural resources-temperature, relief and soil characteristics (Arnaudova, 2008; Popov, 1997; 1998). The used method is based on eliminated the insufficient territories to vine growing requirements. Implementation of AHP method to achieve the viticulture suitable locations enable to the combination of different and complex interdisciplinary factors. The importance of each analyzed parameters are realized by pair wise comparison. As a result different methods were compared and pair wise comparison method is identified as the most appropriate method of weighting for vineyard spatial analysis.

Using AHP models for vineyard environmental assessment combine diverse natural resources as well as climate characteristics, soil parameters and topography factors, which influence on vineyard location for realizing profitable wines.

Some of the most spread and studied parameters influenced on vineyards site selection is the topography of the investigated territory. The topography factors are used to define and describe physical features of the land (natural and built) and related characteristics that are significant to site selection. Topography of a certain region can mainly be described by altitude (both relative and absolute), slope and aspect. Information types can include - mapped spatial features, images, attributes. Raster data will be used for continuous information such as slope and aspect. Vector data will be used for point, linear or polygonal features such as water races or buildings. Landform can be represented by a digital elevation model (DEM), obtained by acquiring data from existing sources of land information, from topography maps, or by direct survey (Eastman, 2009). Contours, slopes and aspects are all generated from the basic elevation model. Comparative heights or elevations are also important, maybe more so than actual altitudes, for example relative

height above a valley floor can affect cold air drainage, or fall from a main water source may provide gravity supply. Annual average temperature is a function of altitude i.e. decreases 0.5°C for every100 m, and which leads moderately cool climate and good temperature conditions in certain heights or frost in higher mountains, limiting the cultivation. Site aspect, defined as the compass direction of slope, relatively influences the local climate (Jackson, 2008; Jones et al., 2002; Wolf et al., 2003). So, it is essentially to combine all topography characteristics in one spatial analysis by using AHP to determine suitable vineyard sites location. Implementation of all relief parameters into AHP method and the results are presented by the next table (Table 1).

Table 1. Weights of topography parameters

Factors	Elevation	Slope	Aspect	SUM	AVERAGE	CONSISTANCY MEASURE
Elevation	0.16	0.38	0.14	0.67	0.22	3.16
Slope	0.05	0.13	0.17	0.35	0.12	3.05
Aspect	0.79	0.50	0.69	1.98	0.66	3.40
SUM	1.00	1.00	1.00	3.00	1.00	
					CI	0.10
					RI	0.58
					CR	0.18

Accordingly, to the resulted weights (average value) done by pair wise comparison of each researched factors, the most importance topography parameters for vineyard site selection is the aspect with its 0.66 value. Next influence place is for the elevation (0.22) and finally the slope impact (0.12). So, it is the most essentially for vineyards territories to be on south aspect, then elevation not to be more than 600m for all Bulgarian regions. Slope is less important, because vineyards can be cultivated from 1 up to 20° and the land can be transformed by terracing.

Geology and soil also control the vine quality indirectly through influence on soil composition, geomorphology, and capability of retention of water (Huggett, 2006). Soil properties affect vine performance which is mainly described by survival and growth, root function and fruit quality and management (Lanyon et al., 2004). Several years may elapse before observing significant alternation to, or its interactions with the grape vine. Relatively uniform, mild-climate soils were considered in the above analysis of land suitability for viticulture together with four soil properties: depth, organic matter, pH and texture were identified with descending importance respectively. Parallel studies on site selection had also referred to internal water drainage as a driver of root growth and steady water supply (Kurtural, 2002). Organic matter content of the soil is an important parameter related to soil fertility. Soil pH is considered as an indicator of fertility, nutrient balance and toxicity (Jones et al., 2004) while soil moisture is an indicator of many factors such as vegetation growth, drought stress, rate of internal water drainage and water holding capacity. Other authors (Wolf et al., 2003) further extended the significance of soil properties including soil depth, bulk density, soil fertility, organic matter, soil texture, soil biology, and origin of soil and surface characteristics for vineyard site selection.

So, the study presents the importance of soil parameters, calculated by AHP analyses and it contains soils profiles, including the surface or topsoil, and the deeper soil or subsoil profiles (where vine roots penetrate and seek water and nutrients), and relevant geological information. Soils are the most commonly described components of '*terroir*' (Wilson, 1998) and are given high priority in the search for suitable sites. Therefore, soil characteristics can be considered as holding one of the most important sets of site selection criteria and data, and be weighted accordingly by AHP. Soils data may be acquired from existing maps, probably in raster format scanned from soil maps, zoned for various categories. If this is insufficient in detail or scale or extent then further survey work may be required, perhaps from scanned images or plotted by survey. Using pair wise comparison methodology to analyse the most important soil factors are presented by the Table 2.

To achieve profitable vineyards location in Karlovo region, Bulgaria the high importance among all analysed soil parameters come down to the soil depth. The minimum depth of topsoil level is between 3-5 m.

Table 2. Weights of soil parameters

Factors	Soil depth	Soil reaction (pH, H_2O)	Soil texture	Organic matter content	Sum	Average	Consistency measure
Soil depth	0.60	0.66	0.54	0.41	2.21	0.55	4.30
Soil reaction (pH, H_2O)	0.20	0.22	0.32	0.29	1.04	0.26	4.30
Soil texture	0.12	0.07	0.11	0.24	0.54	0.13	4.07
Organic matter content	0.09	0.04	0.03	0.06	0.22	0.05	4.06
SUM	1.00	1.00	1.00	1.00	4.00	1.00	
						CI	0.07
						RI	0.9
						CR	0.08

Soil depth distribution presented the opinion of vine roots to grow into deep soil layers and to provide all necessary components. Next importance is to the soil reaction (pH) with its 0.26 points, followed by soil texture (0.13) and organic matter content (0.05). The last one can be modified and increase by additionally fertilization, so it can be changed according to the vine sorts by human actions. About 30% of vineyards location depends on soil reaction. The territories with acidic soils are not suitable for vine cultivation. For profitable yields of grape growth and long-lived vineyards cultivation, the soil reaction is good to be amount between 6.6-7.5 values. Accordingly, to the soil texture, the vine developing is high reached on sandy clay soils, with clay content around 30%. To gather the most suitable vineyards microzoning it is essentially to know the adequate soil depth and the soil reaction in the studied area.

One of the most critical and important components of vineyards location is the climate of the studied region (Jones et al., 2000). Among all climatic variable's temperature is of predominant importance (Jackson, 2008) as a measure of heat sum (Winkler et al., 1962) which is calculated as the base of 100C below which almost no shoot can grow general. Extreme values of temperature throughout the viticulture cycle such as frost occurrences in spring and fall, limiting factors on photosynthesis and respiration in maturing, ripening and harvesting periods, as cold or winter injuries (as opposed to the winter hardiness) when becomes negative values (Jackson, 2008; Jones et al., 2004; Kurtural et al., 2002). General climate is determined simply by country or latitude band, on abroad scale. Macroclimate is in regionally typical climate zones and characteristics. These may fluctuate or change an important consideration in long-term suitability of sites (Smith, 2002). Weather and ongoing need for monitoring events & patterns for vineyard management can be incorporated here. There are some categories included in: temperature, annual precipitation, minimum temperature in the coldest month and maximum temperature in the warmest month, mountain/river influence. All these parameters are pair wise compared by AHP method and the results are presented by the next table (Table 3).

The suitability of vineyards areas highly depends on total vegetation temperature, so in the AHP analyses it takes the first place of importance with weight of 0.39 points. It is almost 40% major influence on the vine cultivation. The vineyards are going well grow between 3500-400°C total vegetation temperatures.

If the temperatures are under these values, the studied regions are not suitable for viticulture. The next level of substantial is presented by annual precipitation - 0.32 points of weight. It presents the cumulative amounts through seasons, patterns of rainfall, events and timing. This factor can be moderate and improved by some kind of irrigation.

Minimum temperature in the coldest month and maximum temperature in the warmest month are critically significant parameters accordingly to the different sorts of vine and the final production of wine. Theirs influence is calculated to the 0.13 and 0.12 value of weight, compared to other parameters. The minimum temperature in the researched area has to be more than 10°C and the maximum temperature has not to be more than 28°C about the Bulgarian climatic zones.

In these critical values on temperature the vine stopping its growing and it reflects on the grape quality and the wine taste. Influence of nearly located mountains and rivers or sea is arranged to the last position (0.04 points), because it is associated with land structure and act on average daily temperatures.

Table 3. Weights of climate parameters

Factors	Total vegetation temperature	Annual precipitation	Minimum temperature in the coldest month	Maximum temperature in the warmest month	Mountain/river influence	SUM	AVERAGE	CONSISTANCY MEASURE
Total vegetation temperature	0.44	0.55	0.41	0.27	0.29	1.96	0.39	5.52
Annual precipitation	0.22	0.27	0.41	0.45	0.24	1.59	0.32	5.77
Minimum temperature in the coldest month	0.11	0.07	0.10	0.18	0.19	0.65	0.13	5.50
Maximum temperature in the warmest month	0.15	0.05	0.05	0.09	0.24	0.58	0.12	5.12
Mountain/river influence	0.07	0.05	0.03	0.02	0.05	0.22	0.04	5.20
SUM	1.00	1.00	1.00	1.00	1.00	5.00	1.00	
							CI	0.11
							RI	1.12
							CR	0.09

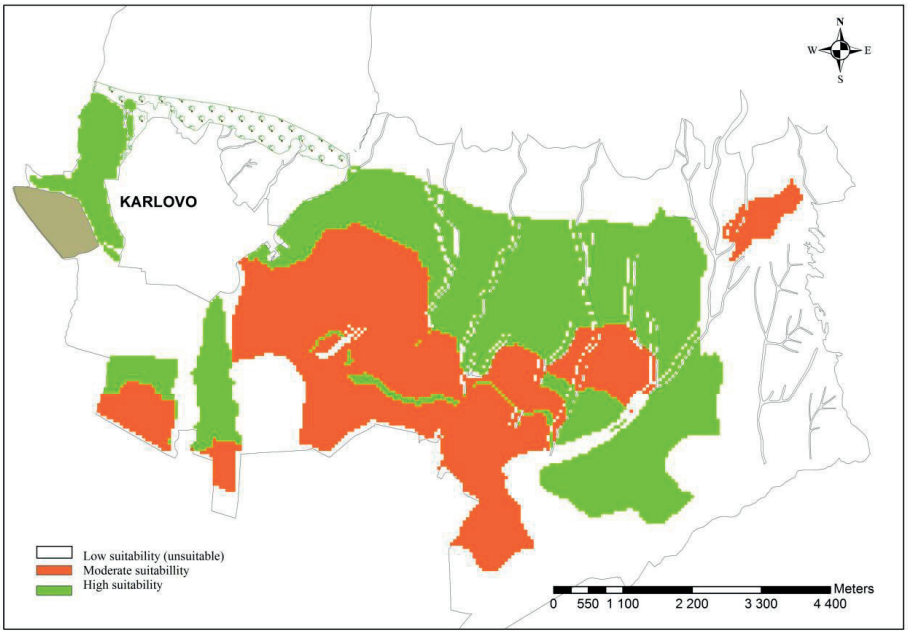

Figure 1. Assessment thematic map of soil resources of Karlovo region, Bulgaria

Land, soil and climatic parameters of given area has variability in certain range. Fluctuation of this range could cause change in growth and development of vegetable crops effecting is final yield.

Parameters are categorised in potential ranges according to needs of the crops (Arnaudova et al., 2010; 2011). The variety of data is collected by different sources and implemented in GIS platform. The results of Karlovo region about the soil analysis are presented on the assessment soil thematic map (Figure 1).

The distribution of soil resource characteristics is performed by suitability located areas for profitable viticulture. Current vineyard areas were determined using AHP method and their spatial distribution compared with the resulting suitability map to determine the current

suitability. Comparison showed vineyards were mostly established in locations where suitability soil map expresses high capability.

CONCLUSIONS

In order to characterize the viticulture potential, it is necessary to assess the suitability of all environmental and ecological factors that influence the quality of the grapes and wines. Climate, topographical and soil suitability determines environmental assessment of the viticulture potential and suitability assessment.
In this paper the AHP method is used to help an investor to select the location of a vineyard for the production of high-quality wine. The method has the advantage of being able to systematically and reliably analyse multiple environmental criteria. The problem relating to the case study is of great conceptual complexity due to the large number of criteria which had to be taken into account by the AHP. According to the studied region of Karlovo, Bulgaria, the most suitable territory for viticulture is 78% and it is presented by assessment thematic map about distribution of soil vine requirements for white wine production. All area is analysed by AHP method and the sites are suitable for cultivation of vineyards for profitable white wines.
The combination of various and complicated technologies - GIS tools, AHP method and well-established techniques- soil mapping, climate studies, topographic parameters, increases the range and types of data available for analyses of vineyard sites.
This paper explores the aspects of site selection or vineyards zooning that are distinctive to viticulture and can be implemented into complex rated methods for suitability assessment.
Issues that are addressed include significance of location, natural and manipulated factors that affect production and quality, important information to support from spatial systems and the probability of success improved, by the use of spatial information for profitable viticulture practices and management.

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